A Study of the Structure of the Near-Coastal Zone Water Column Using Numerical Simulations

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LONG-TERM GOAL

Our long-term goal is to understand how flows in near-coastal zone (20m to 100m) respond to a variety of forcing mechanisms including tidal pressure gradients, surface waves, surface heating and cooling, surface wave-bottom current interaction, and tidally generated bottom boundary currents. Because the nature of this response varies throughout the water column and depends strongly on the non-linear coupling of stratification, turbulence and flow structure characterizing the structure of the water column in this environment is a very difficult field measurement task.

OBJECTIVES

It is possible to gain some insight into the physics, and into our ability to model or parameterize the physics, by looking at a more idealized version of this problem using large eddy numerical simulations (LES). We are performing simulations of the mixing processes in the upper layer of the near-coastal, and deeper, using a periodic channel as the computational domain. Benefits of using numerical simulations, as compared to laboratory or field experiments, is the relative ease with which information about the turbulence can be extracted from the flow and the control over the external variables. The study has two fundamental goals: (1) Developing deeper understanding of the interaction between various physical mechanisms that affect the dynamics of the upper mixed layer in the near-coastal ocean and the deep ocean; and (2) Developing improved parameterizations of these processes for use in large eddy simulations (LES) and Reynolds-Averaged Navier-Stokes (RANS) models to be used in modeling on the larger scales.

APPROACH

The LES technique is employed to solve the Navier-Stokes equations for the turbulent channel flow numerically. The code that is being used in this study is based on one developed by Garg (1996). This code, which was originally developed and implemented on the 400 node Intel Paragon XP/S supercomputer at SDSC by Garg et al. (1994), is being modified to account for the additional physical phenomena we wish to include in our proposed simulations, such as Langmuir circulations. In this regard we are relying heavily on the work of Zhou (1999). Each improvement is being validated

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14. ABSTRACT

Our long-term goal is to understand how flows in near-coastal zone (20m to 100m) respond to a variety of forcing mechanisms including tidal pressure gradients, surface waves, surface heating and cooling, surface wave-bottom current interaction, and tidally generated bottom boundary currents. Because the nature of this response varies throughout the water column and depends strongly on the non-linear coupling of stratification, turbulence and flow structure characterizing the structure of the water column in this environment is a very difficult field measurement task.

15. SUBJECT TERMS

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against basic test cases. The specific tasks are as follows: (1) to increase the Reynolds number of the flow; (2) to add Craik-Leibovich vortex forcing, to allow simulation of Langmuir circulations; and (3) to add a depth-dependent heat source, in order to simulate radiative heating and cooling. For the turbulent cases, we used a large eddy simulation approach that models the sub-grid stresses with a dynamically determined Smagorinsky constant. We are currently using the dynamic eddy viscosity model of Germano et al (1991) with Lilly's (1992) least squares modification. More recently, attention has been focussed on velocity estimation or deconvolution models (Shah and Ferziger, 1995; Domaradzki and Saiki, 1997, and others). In this approach, an attempt is made to estimate the subgrid scale velocity field from the resolved field and to use that estimate to predict the behavior of the small scales of the turbulence. Our group (Katopodes et al, 2000) has recently developed such a model that is much simpler and cheaper to use than the ones just cited and, according to a priori tests, looks very promising. We intend to use it and compare the results with some of the models we have already tried. These, more robust, SGS models will be tested as part of our effort to improve our parameterization of the sub-grid-scale processes for large-scale simulations of the ocean mixed-layer.

WORK COMPLETED

This past year has been a transition year of sorts for this project. We have just completed the final stages of implementing a parallelized Navier-Stokes code for solving stratified, turbulent channel flows on a 40 CPU Compaq/Alpha Beowulf cluster using MPI, by partitioning the grid across processors (http://fluid.Stanford.EDU/mccuencenter/baywulf.html) . Some initial runs have been completed. We have used the results from our previous numerical simulations of stratified sheared homogeneous turbulence (Holt et al., 1992, Shih et al., 2000), stratified channel flows (Garg et al, 2000), and a stratified, turbulent mixing layer (Briggs et al, 1998) to develop modifications to existing turbulence closure schemes such as k-ε and Mellor-Yamada for stratified flows. The initial work has focused on finding possible relationships between the constants used in these models and local turbulence parameters such as turbulent Froude number (Fr_t).

RESULTS

1.   LES of Stratified Channel Flows

We are currently developing flow databases for stratified channel flows at a Reynolds number of 360 (twice the Reynolds number previously achieved by Garg et al. (2000)) using a 128x256x128 grid. Because of grid resolution and the Reynolds number these calculations are extremely taxing on computer resources even in massively parallel mode. We are doing calculations for the following flow conditions (all at Reynolds number of 360):

(i)   Richardson number, Ri =0 (the base case)

(ii)   Richardson number of 60 based on a linear stratification of the full channel depth

(iii)   Richardson numbers of 15 and 60 based on a mid-depth thermocline

(iv)   Mid-depth thermocline (Ri = 15 and 60) with Craik-Leibovich vortex forcing at the surface

2. New Model for Turbulent Stratified Flows

We have used the data derived from the simulation homogeneous sheared turbulent flow to improve the parameterizations used to predict turbulence in the ocean. We chose to use the well-known k-ε parameterization as the basis as it is the one most commonly used for flows of this kind. A buoyancy term has been added to the dissipation equation and some of the coefficients have been allowed to be functions of a quantity that measures the importance of the stratification: either the turbulent Froude number, Fr_t, or the 'Activity Number', ε/vN^2. We have used both the turbulent Froude number and the 'activity number' as correlating parameters and find that both of them seem to be capable of correlating the available data. Field data (Stacey, private communication), however, indicate that the Froude number may be the better choice. In Figure 1 an example of the relationship between model coefficients in the k-e model, and parameters that characterize stratified turbulence is provided. Here $C_{\varepsilon 3}$ is cor with very good accuracy to Fr_t over a wide range of Froude numbers.
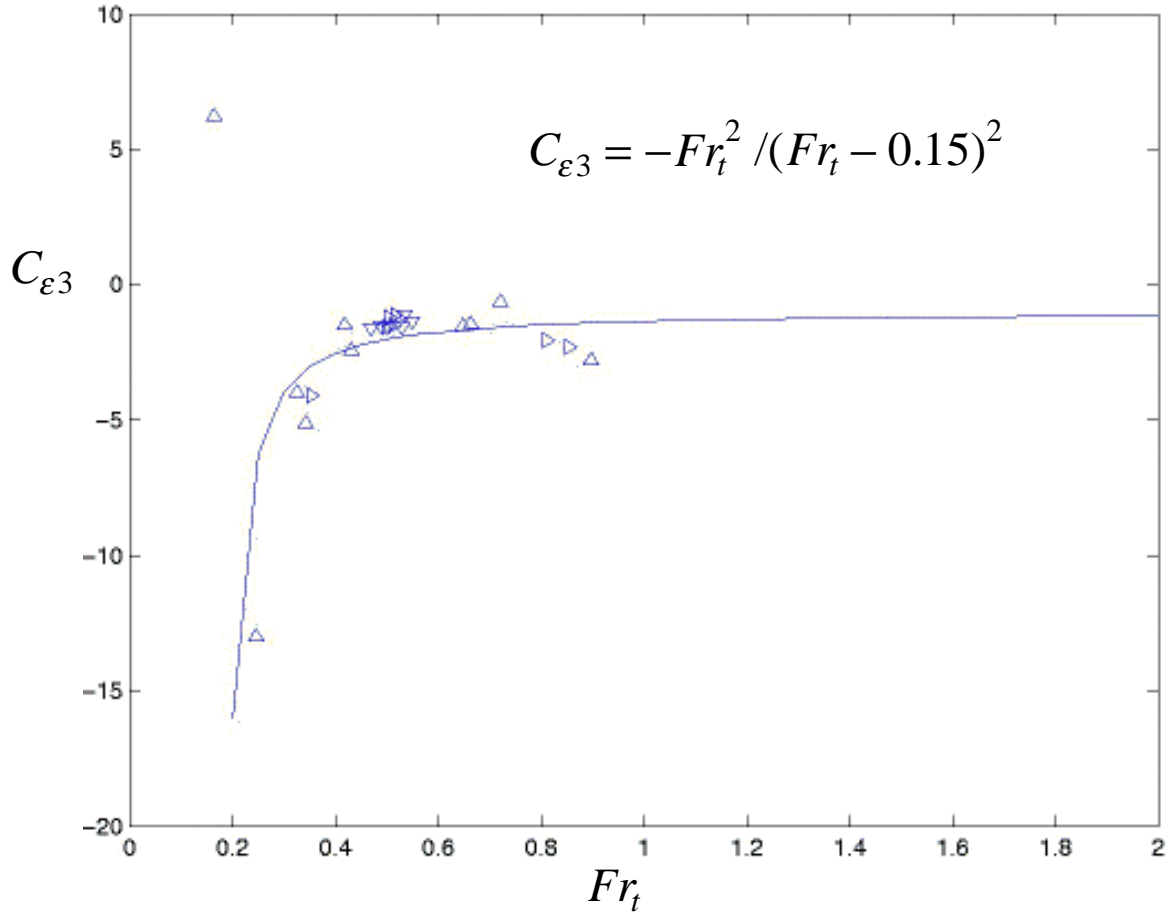

$$C_{\varepsilon 3} = -Fr_t^2 /(Fr_t - 0.15)^2$$

Figure 1: Plot of the Dissipation Buoyancy Coefficient $C_{\varepsilon 3}$ as a function of the Turbulent Froude Number Fr_t

IMPACT/APPLICATIONS

The simulations completed demonstrate the intrinsic value of LES in that it allows us to extend the Reynolds number range of our previous DNS calculations while still preserving our ability to examine the extant physics closely. In addition, evaluation of existing turbulence closure models or commonly used sub-grid-scale parameterizations is therefore a lot more complete than with experiments alone.

TRANSITIONS

The numerical data-bases developed have been analyzed by the PI's in other research projects and the data has been used by researchers at other institutions. For example Diamessis and Nomura at UCSD are using the data from the simulations of Shih et al. (2000) to further examine the interaction between vorticity and rate-of-strain in stratified turbulence. In addition, Ivey at the Center for Water Research at the University of Western Australia is using the data to look at parameterizations of turbulent length scales and buoyancy flux in stratified flows.

RELATED PROJECTS

Shear Production and Dissipation in a stratified tidal flow - ONR - (Monismith PI). Our field work includes work on stratified tidal flows in which we are making Reynolds stress measurements using broad-band ADCPs

An Experimental Study of a Breaking Interfacial Wave - NSF- (Koseff PI). In the laboratory we are performing experiments in an attempt to measure the mixing associated with a breaking internal wave at a stratified (two-layer) interface using the wave-generation technique of Rapp and Melville. In this work we are measuring the mixing efficiency associated with such an event

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